SINGLE PHASE GRID CONNECTED PV SYSTEM

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF TECHNOLOGY (DUAL DEGREE) IN ELECTRICAL ENGINEERING

BY

SANJAY KUMAR SOREN

710EE3081

UNDER THE GUIDANCE OF

PROF. SOMNATH MAITY

Department of Electrical Engineering

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CERTIFICATE

This is to certify that the thesis report entitled "SINGLE PHASE GRID CONNECTED PV SYSTEM" submitted by Sanjay Kumar Soren, 710EE3081 in partial fulfillment of the requirement for the degree of Masters of Degree (Dual Degree) in Electrical Engineering during 2014-2015 at National Institute of Technology Rourkela is an authentic work by him under my supervision and guidance.

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ABSTRACT

A single phase grid connected with a photovoltaic (PV) power system that will provide high voltage gain with state model analysis for the control of the system has been presented. First the photovoltaic system is designed and simulated using MATLAB SIMULINK software. The output voltage of a PV array is comparatively low thus high voltage gain is necessary for grid-connection and synchronization. The PV system has been provided with a boost converter which will boost the low voltage of the PV array to high dc-voltage. A steady state model is obtained and is verified with the help of simulation. A full bridge inverter with bidirectional power flow is used as the second power processing stage, which stabilizes the dc voltage and the output current. Further, a maximum-power-point-tracking method is employed in the PV system to obtain a high performance.

Contents

INTRODUCTION

Amongst the renewable source of energy, the photovoltaic power systems are gaining popularity, with heavy demand in energy sector and to reduce environmental pollution around caused due to excess use non-renewable source of energy. Several system structures are designed for grid connected PV systems. Four different kinds of system configuration are used for grid connected PV power application: the centralized inverter system, the string inverter system, the multi-string inverter system and the module integrated inverter system.

The main advantages of using a grid connected PV systems are: effect on the environment is low, the can be installed near to the consumer, thereby transmission lines losses can be saved, cost of maintenance in the generating system can be reduced as there are no moving parts, system's modularity will allow the installed capacity to expand and carbon-dioxide gases are not emitted to the environment.

For small distributed generator system , such as residential power utilization, all the above mentioned types of inverters system other than centralized inverter system are be used. The main problem in the design of the photovoltaic distributed generator system is to obtain high voltage gain. For a typical photovoltaic model, the open circuit voltage is about 20 V and the maximum power point (MPP) voltage is about 16 V whereas voltage of the utility grid is 220 V ac. Hence high voltage amplification is mandatory for grid synchronization and to achieve low total harmonic distortion (THD). In grid-connected PV system power electronics inverters are used for the power conversion, interconnection and control optimization. The steady state analysis and control strategy of the system play a vital role in the grid synchronization. The output of the inverter should be properly sinusoidal for proper grid synchronization. Hence it is clear that inverter required for PV system, high power factor, low THD, fast dynamic response on how the control strategy are adopted for grid inverters.

Ensuring current injected into the grid with low harmonic content and maintain the pahse with the main voltage, the controller must be able to track down maximum power point tracking (MPPT) mechanism using perturb and observe (P&O) algorithm for the PV model which will cause all the available array power to be utilized.

It is mandatory that the most of the solutions designed to attain the PV system tasks such as MPPT, in inverter and Power factor correction are employed at two different stages.

LITERATURE REVIEW

Various algorithms are carried out in the building of integrated photovoltaic system's performance reveal that an average losses of about 20%-25% in electricity production. These are caused mainly due to mismatching losses, partial shadows, and variation in current-voltage (I-V) characteristics, difference in inclination of solar surfaces, and temperature effects. These losses can be minimized by means of suitable electronics devices, a low cost high efficiency dc-dc boost converter with maximum power point tracking (MPPT) functions. Analysis on architecture of grid connected PV system were proposed.

PV inverter, which plays a very important role in the operation of the PV system, is used to convert dc power obtained from the PV array into ac power which would be fed into the grid. The output waveform of the inverter can be improved by reducing its respective harmonic content, and hence the size of the filter used and the interference due to the switching action of the inverter [5]. In recent years, multilevel inverters have become more attractive for researchers and manufacturers due to their advantages over conventional PWM inverters.

The maximum power point tracking (MPPT0 function plays a very important role as the voltage can have a wide range from 15V-40V with variable power capacities for a single PV panel[]. When the input voltage is of wide range, high efficiency is difficult to achive in a single stage micro-inverter. Hence dual stage micro-inverter which combines a step up dc-dc converter and dc-ac inverter is implemented to obtain high efficiency as high as the conventional PV string type inverter[7].

The controller for the inverter contains inner current loop and external voltage loop. The external voltage loop stabilizes the voltage of the dc link capacitor for the inverter and provides the magnitude of the reference current for the inner loop, while the inner loop controls the output current of the inverter to track reference current and meet the requirement of the grid[9].

MOTIVATION

Fossil fuels used for electric power generation has created several problems on the environment including global warming and greenhouse effect. This has led to an era in which the increasing demand of power has to be met by Grid connected system that are based on renewable on sources such as wind, solar and hydro power that are renewable in nature.

The DG systems are distributed near the user's facility. These systems are mainly small scale generations having capacity less than 20MW. These Distributed Generation (DG) systems need to be controlled properly in order to ensure sinusoidal current injection into the grid. However, they have a poor controllability due to their intermittent characteristics. Grid connected inverter is the key element to maintain voltage at the point of common coupling (PCC) constant and to ensure power quality improvements. For safe and reliable operation of power system based on DG system, usually power plant operators should satisfy the grid code requirements such as grid stability, fault ride through, power quality improvement, grid synchronization and power control etc. The major issue associated with DG system is their synchronization with utility voltage vector. The information about the phase angle of utility voltage vector is accurately tracked in order to control the flow of active and reactive power and to turn on and off power devices.

PHOTOVOLTAIC SYSTEM

A photovoltaic (PV) cell is a particular electrical gadget that can change over sun oriented vitality into direct current by photovoltaic impact. It is coordinated piece of sun oriented vitality framework and is an imperative wellspring of option wellspring of vitality. The PV cells are made of silicon consolidated or doped with diverse components to influence the conduct of electrons or openings. Diverse materials, for example, copper indium diselenide (CIS), cadmium telluride (CdTe), and gallium arsenide (GaAs), are produced for utilization in PV cells. In a PV cell, these bits of materials are put together. The gadget is developed in such a route, to the point that the intersection can be presented to obvious light, IR, or UV. At the point when such radiation strikes the P-N intersection, a voltage contrast is delivered between the P sort and N sort materials. Terminals joined with the semiconductor layers permit current to be drawn from the gadget. Metallic contacts are given to associate the heap to the cell. The cell is set under a glass spread joined to it by glue for mechanical assurance. The proficiency of a sunlight based cell fluctuates between 15%-19% and builds up an open circuit voltage of the request 0.65 V and a most extreme current thickness between 35-40mA/cm2.

WORKING PRINCIPLE

Vitality change in sun powered cells works of two vital steps. First and foremost, assimilation of light produces an electron gap pair. The electron and gap are then isolated by the structure of the gadget electrons to the negative terminal and openings to the positive terminal—subsequently creating electrical force.

A perfect sun oriented cell is spoken to by a present source associated in parallel with a correcting diode, as indicated in the identical circuit of Figure 1. The relating I-V trademark is portrayed by the Shockley sun powered cell mathematical statement

$$I_L = I_D + I_{Sh} + I \qquad (1)$$

$$I_D = I\left(e^{\frac{q(V+IR_S)}{KTA}} - 1\right) \qquad (2)$$

$$I = I_L - I\left(e^{\frac{q(V+IR_S)}{KTA}} - 1\right) - \frac{V+IR_S}{R_{sh}} \qquad (3)$$

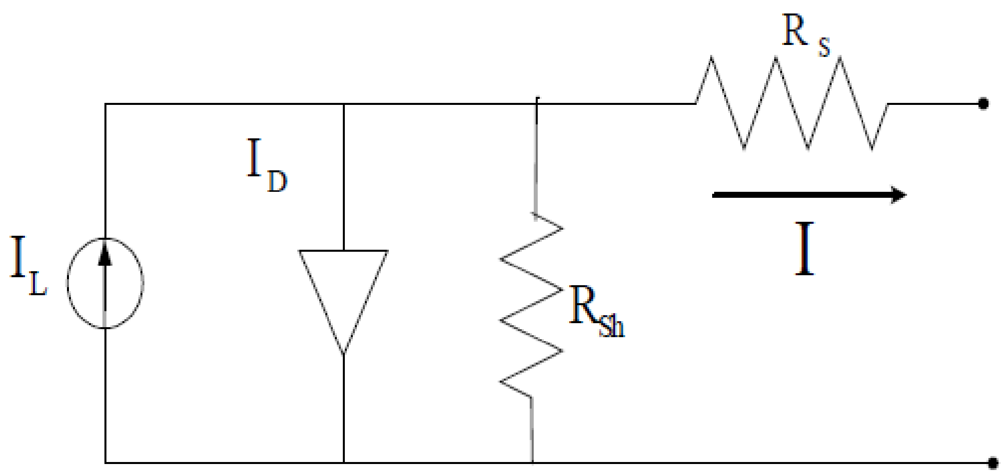

Fig-1. Equivalent circuit of a solar cell

V_O: voltage appearing across diode.

V: load voltage.

I: Cell Current (A)

$R_{S:}$ internal (series) resistance of the system.

I_O: Reverse saturation current of the diode.

T: Temperature in kelvin.

K: Boltzmann constant (1.38 x 10-23 J / K).

n = Ideality factor (≈1.92).

q: electronic charge (1.6 x 10-19C).

The output of the solar cell i.e. the P-V and I-V curve is given in the following figure.

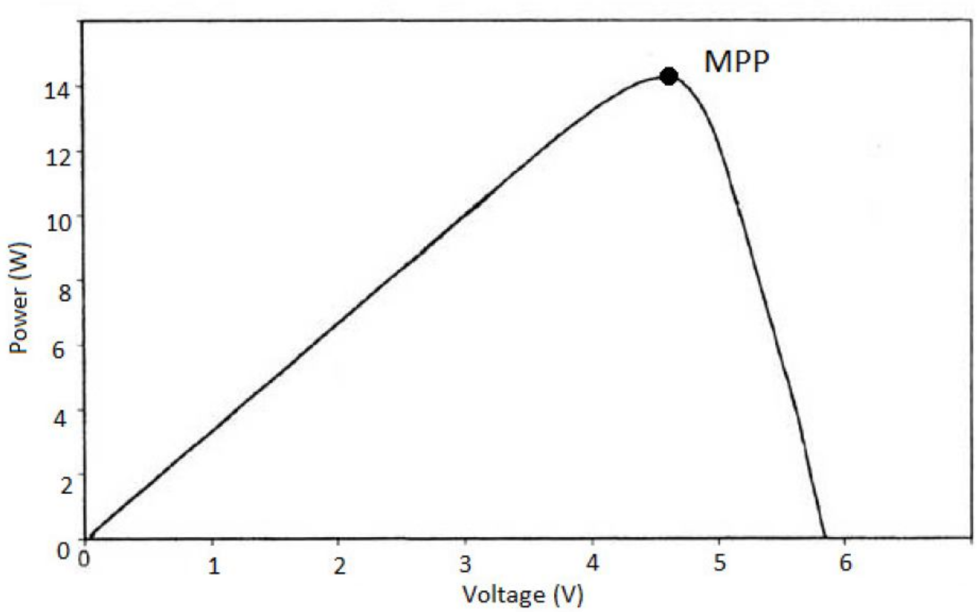

Fig-2. P-V Characteristics

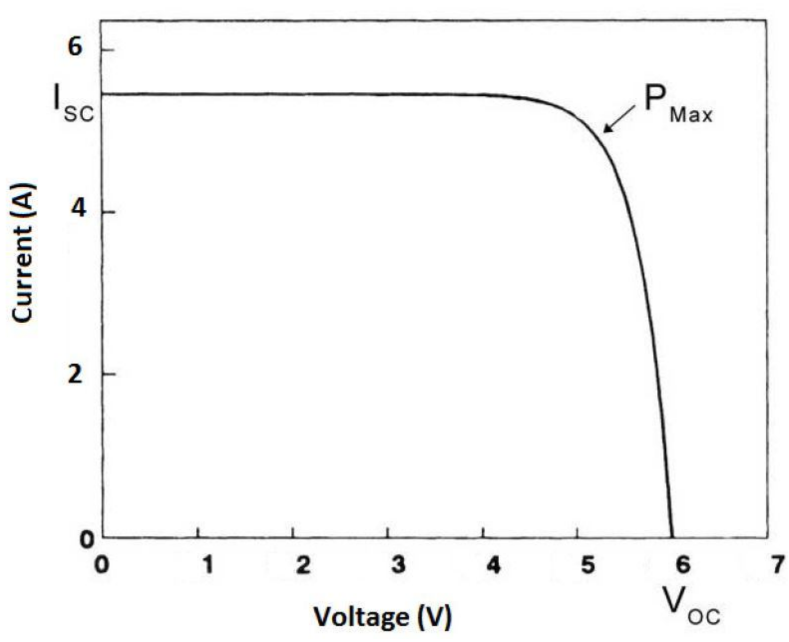

Fig-3. I-V Characteristics

MAXIMUM POWER POINT TRACKING

The efficiency of a solar cell is low. With a specific end goal to expand the efficiency, routines are to be undertaken to match the source and load appropriately. One such strategy is the Maximum Power Point Tracking (MPPT). This procedure is utilized to acquire the most extreme conceivable force from a fluctuating source. In photovoltaic frameworks the I-V bend is non-direct, along these lines making it hard to be utilized to power a certain heap. This is finished by using a help converter whose duty cycle is differed by utilizing a mppt algorithm.

METHODS FOR MPPT

There are different methods to track down the maximum power point, a few of which are listed below:

- Perturb and Observe method
- Incremental Conductance method
- Parasitic Capacitance method
- Constant Voltage method
- Constant Current method

Perturb and Observe Method

Perturb and Observe is the most regularly utilized MPPT strategy because of its simplicity of execution. The working voltage is expanded the length of (dP)/dV is sure, i.e. the voltage is expanded the length of we get more power. On the off chance that (dP)/dV is detected negative, the working voltage is diminished. The voltage is kept put if (dP)/dV is close to zero inside of a preset band. The time multifaceted nature of this calculation is less however on coming to near to the MPP it doesn't stop at the MPP and continues annoying. This calculation is not suitable when the variety in the sun oriented illumination is high. The voltage never really achieves a careful esteem yet annoys around the most extreme force point (MPP).

3.1.2. Incremental Conductance Method

In this strategy the PV exhibit's incremental conductance dI/dV to figure the indication of dP/dV. At the point when dI/dV is equivalent and inverse to the estimation of dP/dV (where

dP/dV=0) the calculation demonstrates that the greatest force point is come to and it is ended and gives back the comparing benefit of working voltage for MPP. This strategy tracks quickly changing illumination conditions more precisely than P&O.

P = V*I

Differentiating w.r.t. voltage

$$\frac{dP}{dV} = \frac{d(V*I)}{dV} \qquad (4)$$

$$\frac{dP}{dV} = I + V * (\frac{dI}{dV}) \qquad (5)$$

When maximum power point is reached $\frac{dP}{dV} = 0$. Hence,

$$\frac{dI}{dV} = -\frac{I}{V} \qquad (6)$$

3.1.3. Parasitic Capacitance Method

This method is an improved version of the incremental conductance method, with the improvement being that the effect of the PV cell's parasitic union capacitance.

3.1.4. Constant Voltage Method

This strategy is not broadly utilized as the misfortunes amid operation is subject to the connection between the open circuit voltage and the greatest influence point voltage. The proportion of these two voltages is for the most part consistent for a sun oriented cell, generally around 0.76. Consequently the open circuit voltage is acquired tentatively and the working voltage is acclimated to just 76%.

3.1.5. Constant Current Method

It is like the consistent voltage technique, this strategy is subject to the connection between the open circuit current and the most extreme force point current. The proportion of these two streams is by and large consistent for a sun based cell, generally around 0.95. In this manner the short out current is acquired tentatively and the working current is acclimated to 95%.

Flowchart of MPPT Algorithm

Perturb and Observe

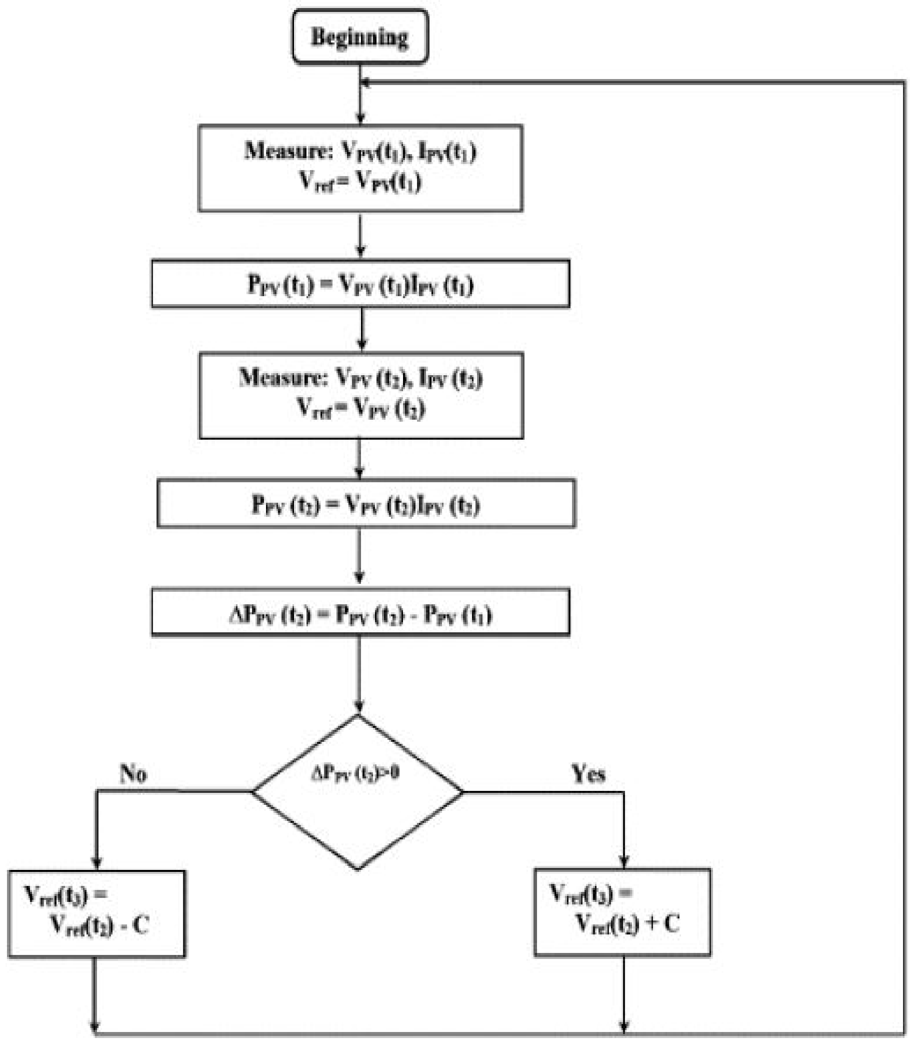

Fig-4. Flowchart of Perturb and Observe

BOOST CONVERTER

As the output of the PV panel is very low and in order to connect it to the grid, its voltage has to be increased. The output of the solar panel is a DC voltage of very low magnitude. Hence a boost converter is required for boosting the voltage to higher level without use of the transformer. The primary parts of a support converter are an inductor, a diode and a high recurrence switch. These in a composed way supply energy to the heap at a voltage more prominent than the information voltage extent. One capacitor is joined over the heap end to keep up the heap voltage consistent.

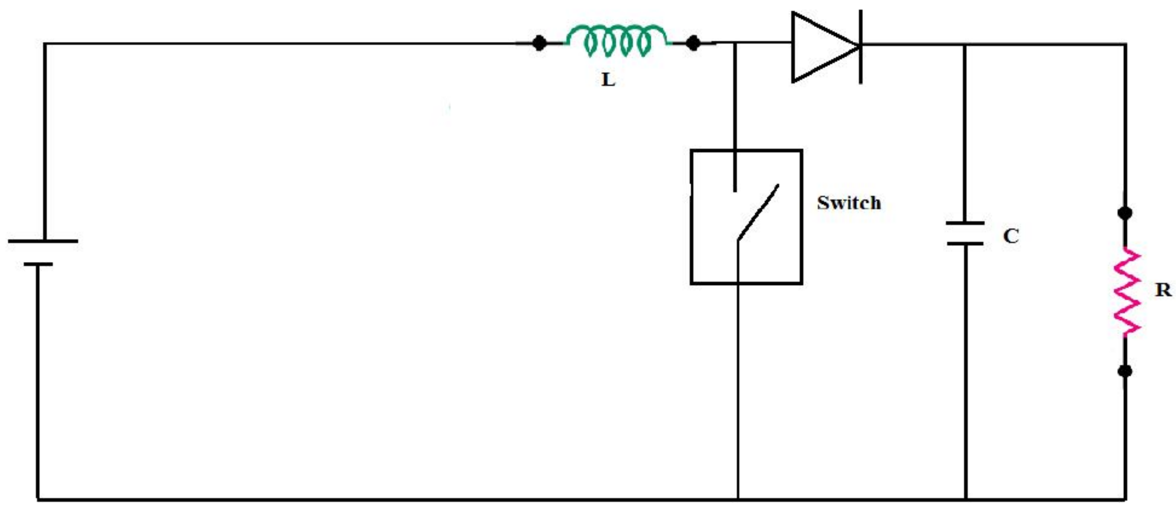

Fig-5. A boost Converter

4.1. Modes of Operation

Two methods of operation are there in a help converter. These are in light of the end and opening of the switch. In the first mode the switch is shut; this is known as the charging method of operation. The second mode is the point at which the switch is open; this is known as the releasing method of operation. The circuit chart of a support converter is given in fig-5.

4.1.1. Charging Mode

The switch is shut and the inductor is charged by the source through the switch. The charging current is exponential in nature and for straightforwardness it is thought to be straightly fluctuating. The diode limits the stream of current from the source to the heap and the interest of the heap is met by the releasing of the capacitor.

4.1.2. Discharging Mode

In the releasing method of operation the switch is open and the diode is forward one-sided .The inductor now releases and together with the source charges the capacitor and takes care of the heap requests. The heap current variety is little and by and large is expected consistent all through the operation.

INVERTER

Single stage inverters can be both of either square-wave or PWM inverters. The square wave sort is the least complex system to create AC from DC; be that as it may, it experiences low recurrence sounds which causes trouble in sifting through the clamor to keep these music to return back to the essential side of the transformer. The PWM inverter powers the sounds to be up higher than the basic (line) recurrence; consequently the separating necessity of the inverter is minimized.

There are numerous mixed bags of inverter plans. The most well-known topology is alluded to as the H-span topology. Its fundamental setup is indicated in Figure-6. This topology can be utilized with either the square wave, or heartbeat width balance (PWM) exchanging plans.

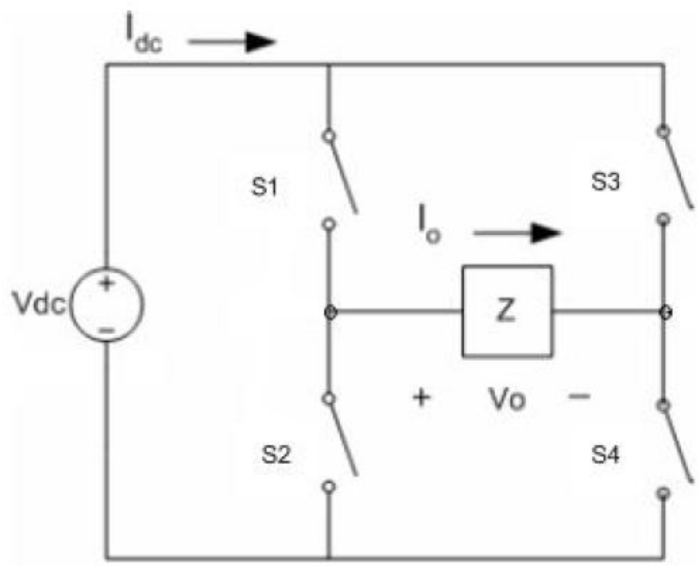

Fig-6. H-bridge Single Phase Inverter

The square-wave exchanging strategy for controlling the switches (marked S1 through S4) with a specific end goal to accomplish a square wave AC yield signal. The AC yield is accomplished by utilizing a control signal with a 50% obligation cycle wired to S1 and S4. An altered duplicate of the same sign is additionally wired to S2 and S3. This exchanging plan guarantees that S1 and S4 are dependably on when S2 and S3 are OFF. It makes a square wave yield as indicated in fig-7. The upside of utilizing a H-span inverter is that just a solitary, basic control sign is obliged to control four transistors. The drawback, nonetheless, is that the square wave yield is a low quality AC signal that infuses numerous music into any heaps to which it is fueling.

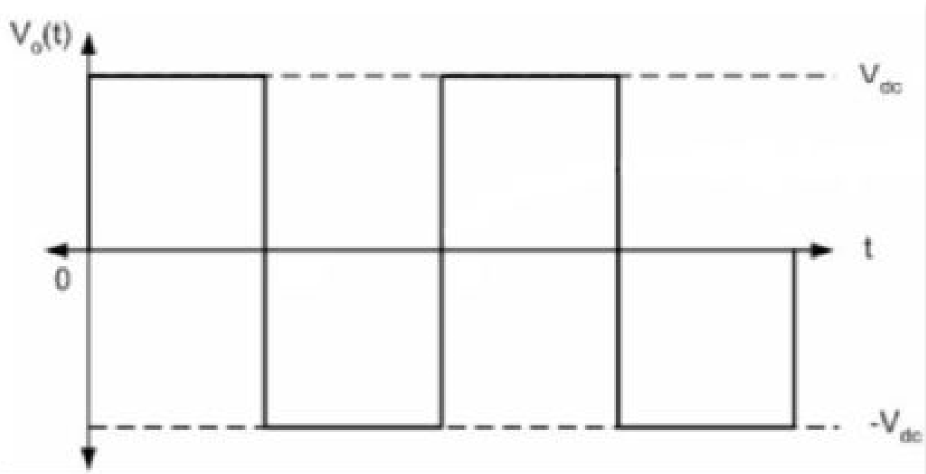

Fig-7. Square wave output of Inverter

PWM control signs can be utilized with the same H-span geology. The disservice of the PWM exchanging plan is that it is more muddled than the square-wave exchanging plan. Different, moderately complex control signs are expected to control the transistors of the PWM inverter. The point of interest, nonetheless, of the PWM exchanging plan is that, it has the capacity create more sinusoidal yield than the square wave sort. The yield of PWM inverter is demonstrated in Fig-8.

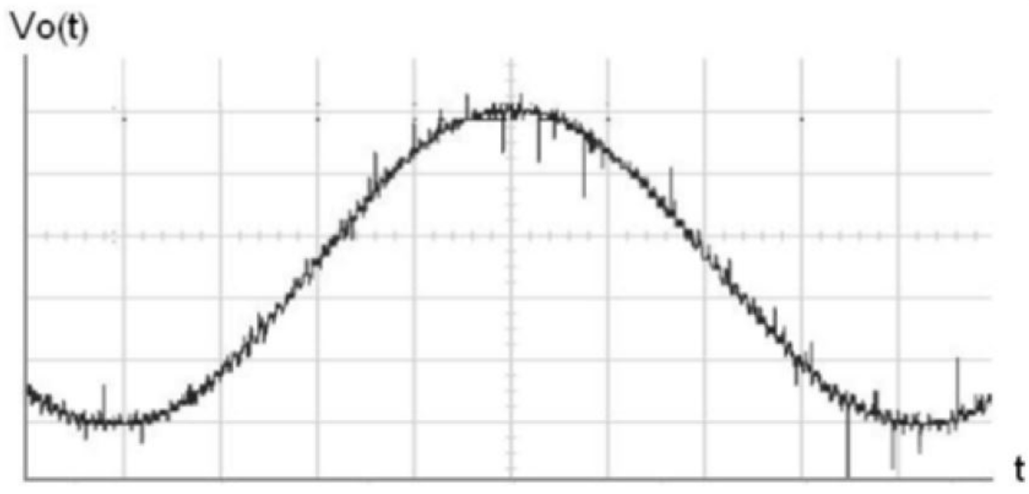

Fig-8. Output of PWM inverter

A proportional – Integral (PI) current control plan is utilized to keep the yield current sinusoidal and to have high element execution under quickly changing environmental conditions and to keep up the force variable at close solidarity. Sinusoidal PWM is acquired by contrasting a high-recurrence transporter with a low-recurrence sinusoidal, which is the regulating or reference signal. The transporter has a steady period; consequently, the switches have consistent exchanging recurrence. The exchanging moment is resolved from the intersection of the transporter and the regulating signal.

5.1. Operation of Inverter

The inverter produces five level yield voltage, i.e., 0, +Vpv/2, +Vpv, −Vpv/2, and –Vpv as in Fig. 9. As demonstrated in Fig. 10, an assistant circuit which comprises of four diodes and a switch S1 is utilized between the dc-transport capacitors and the full-connect inverter. Fitting exchanging control of the assistant circuit can produce half level of PV supply voltage, i.e., +Vpv/2 and −Vpv/2 [6]. Two reference signals Vref1 and Vref2 will alternate to be contrasted and the transporter signal at once. On the off chance that Vref1 surpasses the crest adequacy of the bearer signal Vcarrier, Vref2 will be contrasted and the transporter sign till it achieves zero. At that point Vref1 assumes control over the correlation process until it surpasses Vcarrier. This will prompt an exchanging example, as demonstrated in Fig. 11. Switches S1–S3 will be exchanging at the rate of the bearer signal recurrence, though S4 and S5 will work at a recurrence equal to the major recurrence. Table I shows the level of Vinv amid S1–S5 switch OFF

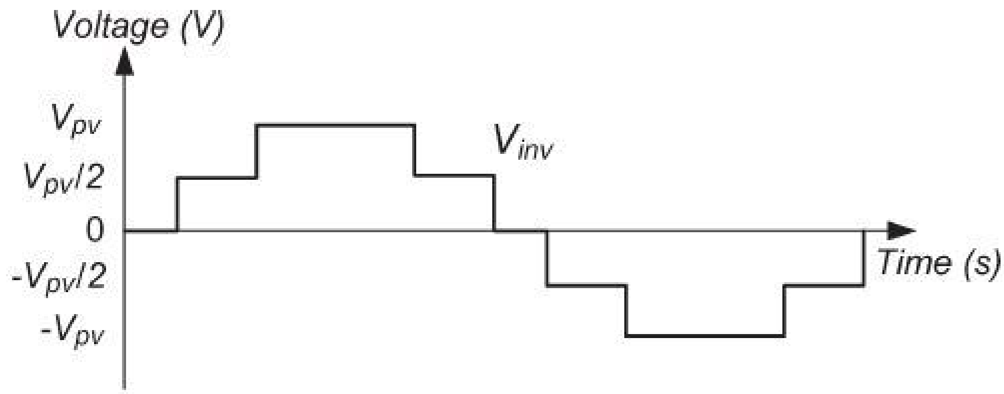

Fig-9. Ideal Inverter output Voltage

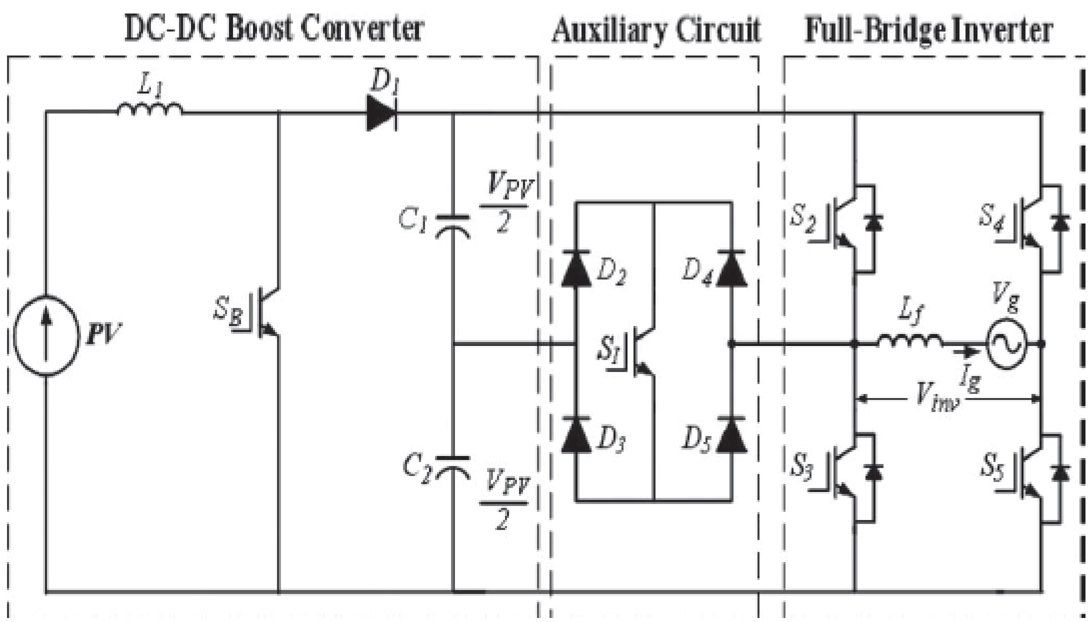

Fig-10. Five level Inverter Topology

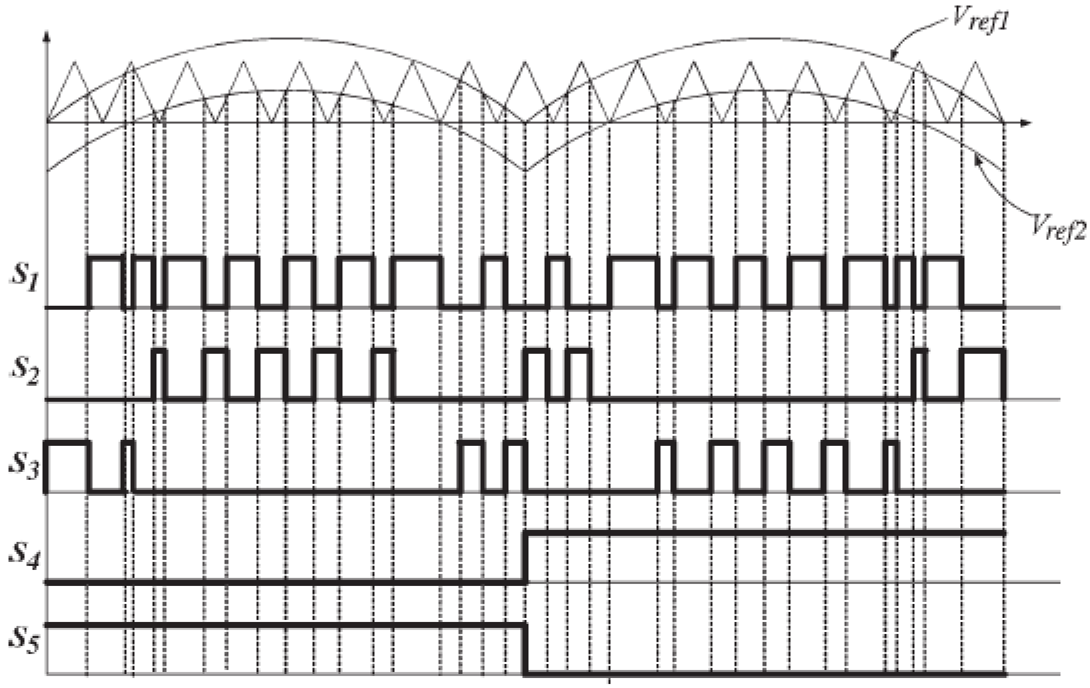

Fig-11. Switching Pattern of Five level single phase inverter

CONTROL STRATEGY OF FULL BRIDGE INVERTER

Utilization of direct current-control system, the VS-PWM converter powers the prompt burden current to precisely take after the sinusoidal reference, which synchronizes with the utility matrix voltage and the powerful element, the low THD and the quick element reaction are accomplished. Moreover, the bidirectional stream of force encourages the remuneration of the dc-transport and the air conditioner side voltage variety which balances out the dc-transport voltage.

S_1	S_2	S_3	S_4	S_5	V_{inv}
ON	OFF	OFF	OFF	ON	$+V_{PV}/2$
OFF	ON	OFF	OFF	ON	$+V_{PV}$
OFF	OFF Or (ON)	OFF Or (ON)	ON Or (OFF)	ON Or (OFF)	0
ON	OFF	OFF	ON	OFF	$-V_{PV}/2$
OFF	OFF	ON	ON	OFF	$-V_{PV}$

TABLE-1. INVERTER OUTPUT VOLTAGE DURING SWTCHING

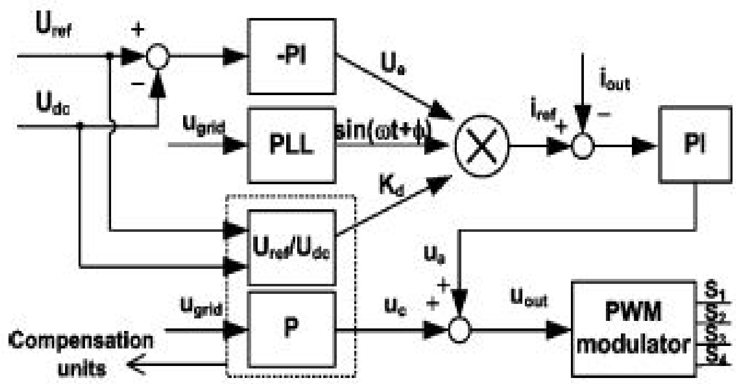

Fig-12. Control Block of Full Bridge Inverter

Fig-12 shows the control block of the full bridge inverter with bidirectional power flow

Control of the Bidirectional Power Flow

With reference to Fig-12, the dc-transport voltage Udc is controlled to keep Uref consistent with zero lapse by the voltage-input control circle. The heading and extent of VS-PWM converter's yield current and force are chosen by the estimation of Ue , which is the yield of negative PI controller in the voltage circle.

On the off chance that Udc > Uref then Ue is expanding, and the VS-PWM converter fills in as an inverter which exchanges the PV cluster energy to the utility network. The vitality era of PV force framework is decidedly associated with the greatness of Ue .

On the off chance that Udc < Uref then Ue is diminishing, and when Ue < 0, the VS-PWM converter functions as a PWM rectifier, which draws the vitality from the utility network to the capacitor of dc transport, keeping up the steadiness of dc-transport voltage. The present in the negative bearing at long last methodologies a little esteem, which is just used to make up for the switch misfortunes of VS-PWM converter.

Direct Current Control with Compensation Unit

The load current iout is identified and contrasted and the reference current iref , and the mistake sign is handled by a PI controller in the present input control circle. The upside of the immediate current control are the low music diminishes misfortunes in relentless state, the quick reaction to give high element exhibitions, and the top current insurance to reject over-burden. For the most part, the present control circle is intended to have a transfer speed of 2–5 kHz, higher than the voltage circle data transmission of 200–500 Hz, to guarantee the solidness of the proposed inverter control with two PI controllers.
The quick power and the dc-transport voltage incorporate a swell part with the recurrence 2ω on account of a solitary stage inverter. Further the framework voltage is not a perfect sinusoidal waveform by and by. Hence, it is difficult to accomplish low THD of the yield current by utilizing the straightforward direct-current-control methodology in the genuine matrix condition. Consequently two pay units are added to the present control circle as food forward control units. The food forward control has little effect on the framework's zeros and shafts setup, yet accomplishes to track the sinusoidal reference precisely and limit the music mutilation of the peak current, particularly at the present.

Compensation coefficient K_d posses the magnitude of reference currents i_{ref} , and counteract the main influences of the dc-bus voltage ripple because K_d represents
a negative fluctuating feature with the frequency 2ω, compared with the dc-bus voltage ripple. K_d is defined as

$$Kd = \frac{Uref}{Udc} \qquad (7)$$

The PI controller in the network voltage-bolster forward control duplicates the genuine, damaged matrix voltage with an extent pick up Kf . Its yield Uc and the yield Ua of PI controller in current input circle are as one nourished to the PWM modulator to deliver the signs for the inverter switches. Hence, the balance wave Uout incorporates the flawed part of lattice voltage to repay matrix voltage vacillation and get sinusoidal current waveform. The food forward impact relies on upon the estimation of Kf .

GRID SYNCHRONIZATION TECHNIQUE

Synchronizations method can be divided into two categories: namely mathematical analysis and PLL based methods. Among them, PLL method is gaining more attention.

A basic PLL consists of a phase detector (PD), a loop filter (LF) and a voltage controlled oscillator (VCO) as shown in fig-13.

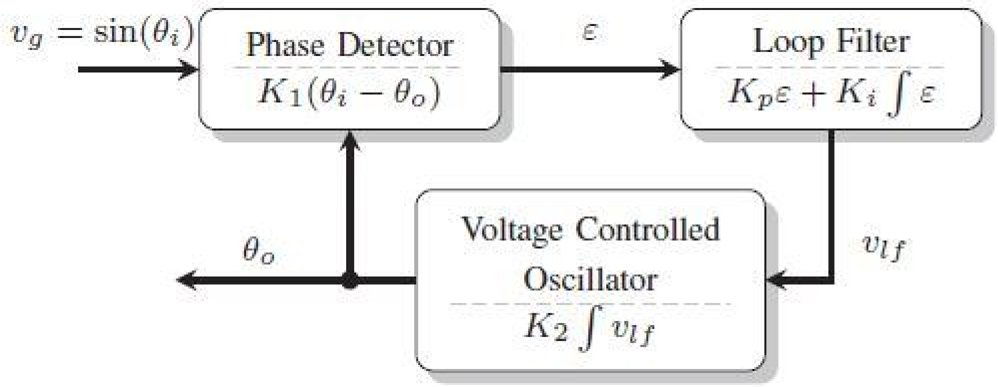

Fig-13. Structure of a PLL

$$\frac{\theta_0(s)}{\theta_i(s)} = \frac{K_1K_2G_{lf}(s)}{s + K_1K_2G_{lf}(s)}$$

$$= \frac{K_1K_2K_Ps+K_1K_2K_i}{s^2+K_1K_2K_Ps+K_1K_2K_i} \qquad ()$$

Where, θ_0, θ_i are output and input phases

K_1,K_2 are the gains of PD and VCO respectively.

$G_{lf}(s)= K_p + K_i/s$ is LF transfer function.

K_p,K_i are proportional and integral gains of LF.

The various kinds of PLL techniques are:

1. Linear PLL

Linear PLL (LPLL) is predominantly utilized for single stage voltage. It has a blender which is utilized as a stage differentiator which gives a sign relative to the contrast between the periods of the data and the yield signal. This mistake sign contains parts at frequencies which are even products of the info recurrence. The circle channel evacuates the consonant parts and just the corresponding segment is gone on to the voltage controlled oscillator as per which the VCO yield is created.

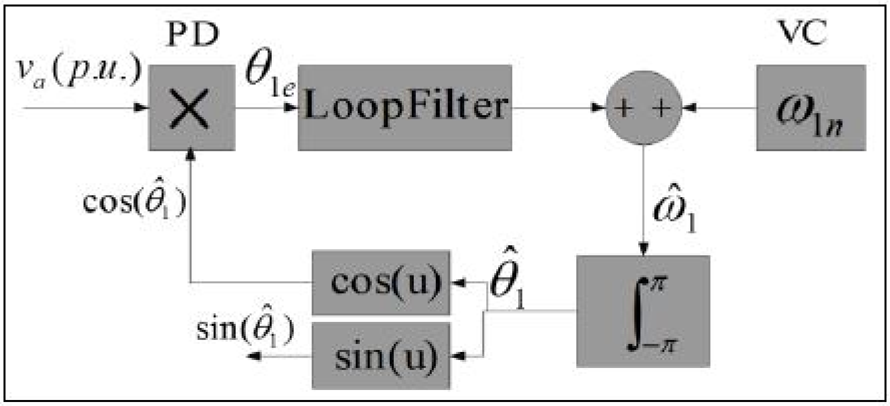

Fig-14. Block diagram of LPLL

2. Synchronous Reference frame PLL

A synchronous Reference Frame PLL (SRF PLL) is utilized for following the stage point if there should arise an occurrence of 3-stage signals which meets expectations in a comparable manner as a direct PLL with just distinction in the Phase Detector (PD) piece. It uses Park's Transformation of a 3-stage motion as the PD. Figure 15 demonstrates the piece outline of a SRF PLL in which Va, Vb, Vc are the parts of a 3-stage signal. To begin with square in the figure is Clarke's Transformation which deciphers a 3-stage voltage vector from the abc common reference edge to the αβ stationary reference outline. The second square is the Park's Transformation which deciphers the αβ stationary reference edge to turning rotating frame.

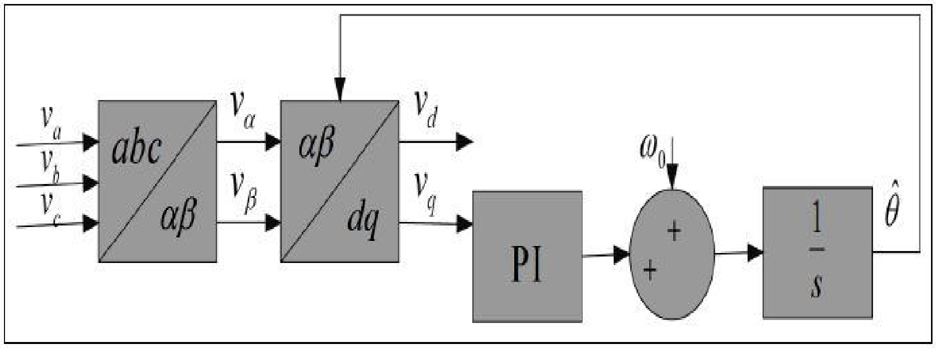

Fig-15. Block Diagram of SRF PLL.

SIMULATION RESULTS

8.1. SIMULINK MODEL OF PV PANEL

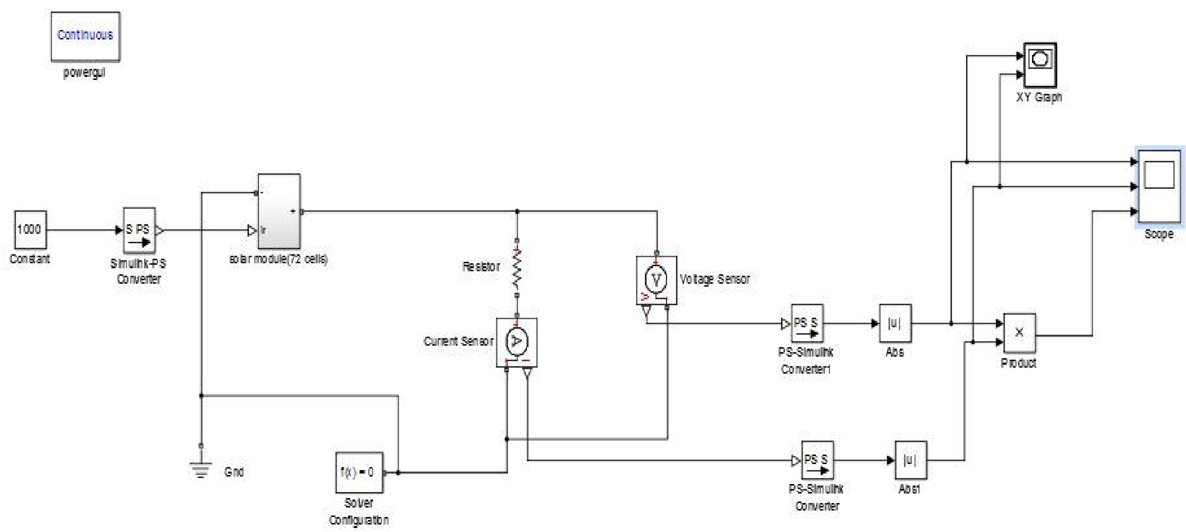

Fig-8.1. PV Model

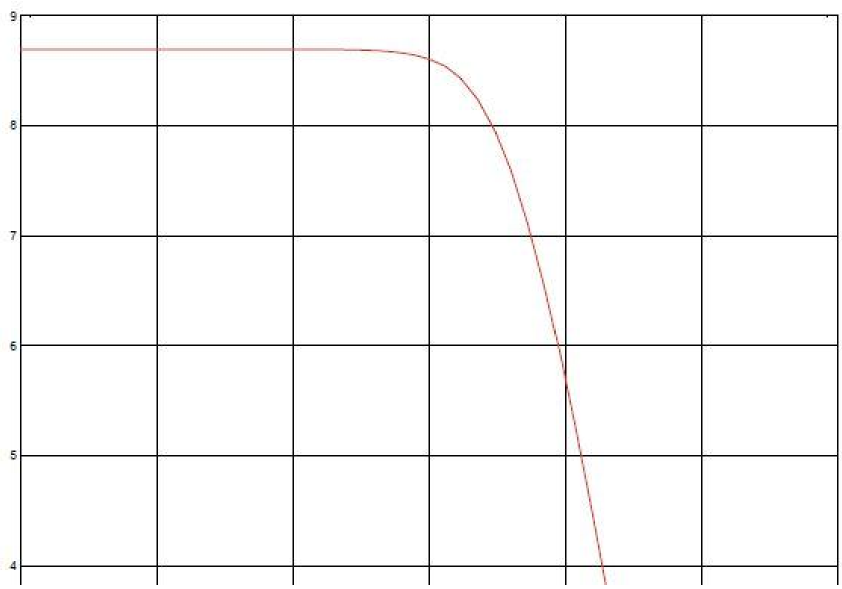

Fig-8.2. P-V Graph

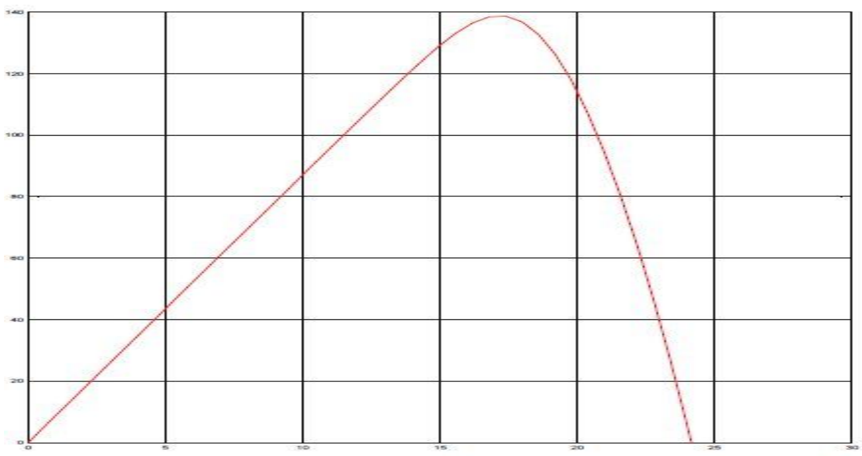

Fig-8.3. I-V Graph

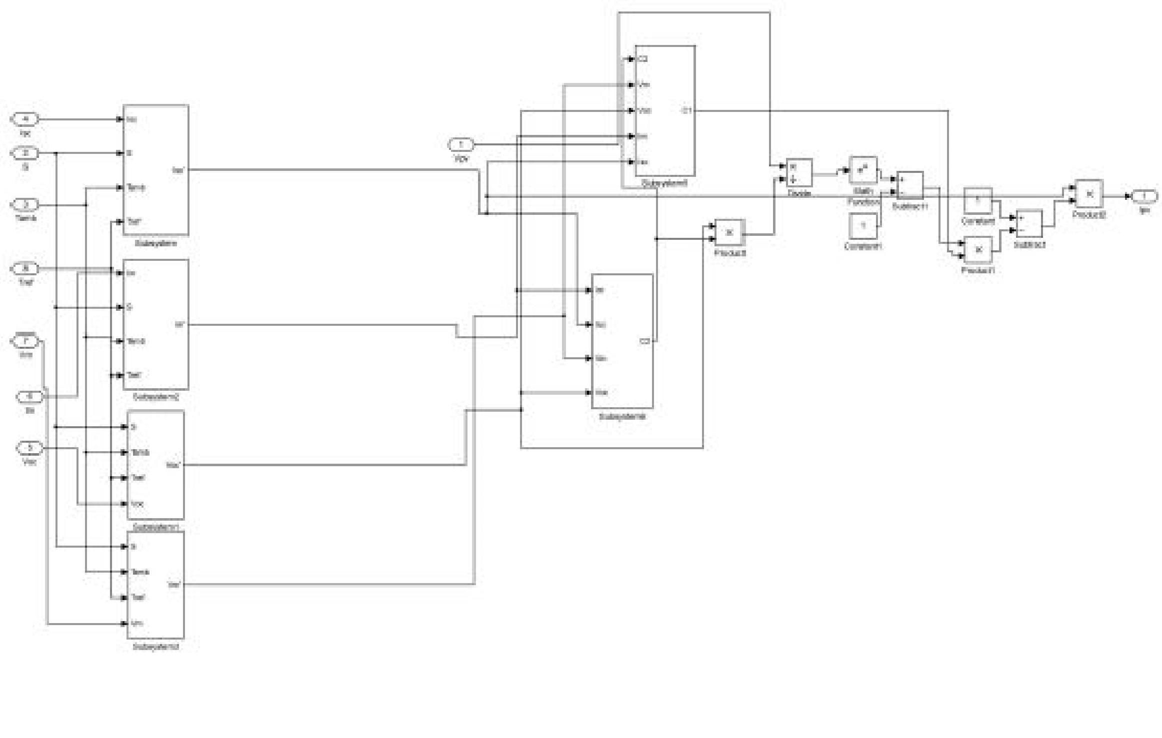

Fig-8.4. Subsystem Of PV Panel

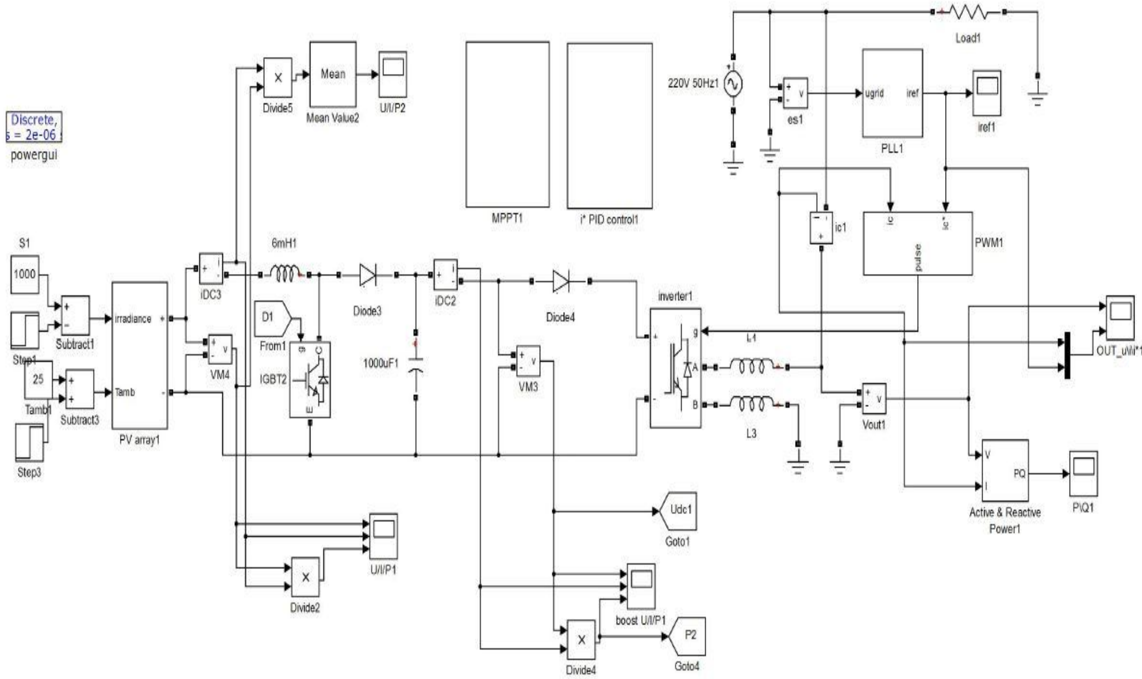

Fig-8.5. Simulink Model of Grid Connected PV System

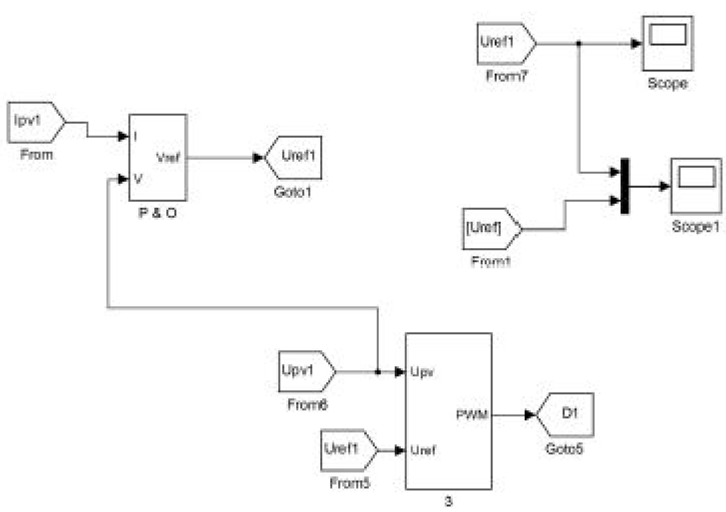

Fig-8.6.Simulink model of MPPT

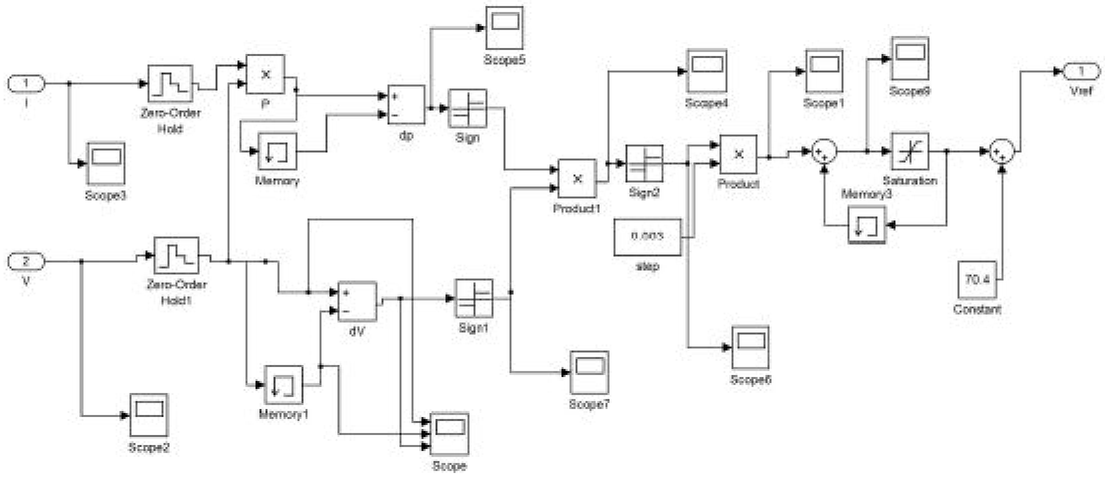

Fig-8.7. Simulink model of Perturb & Observe

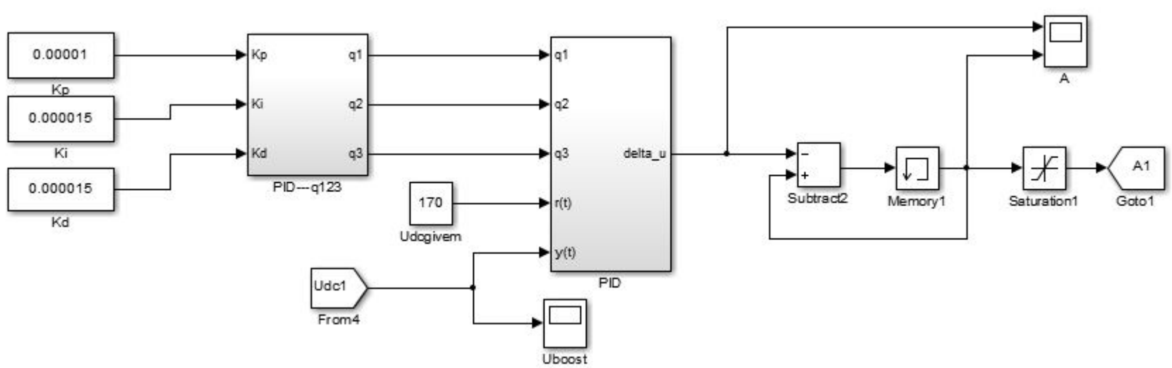

Fig-8.8. Simulink model of PID controller

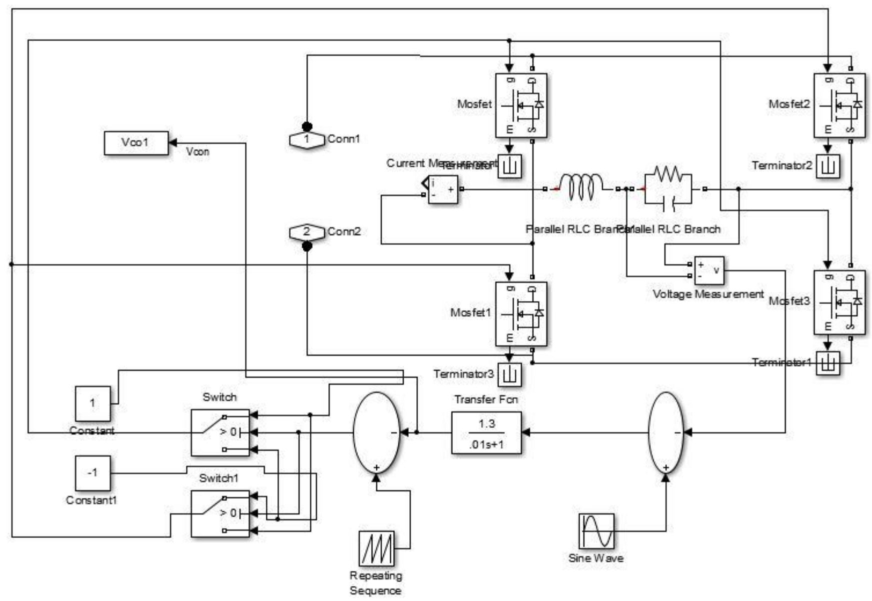

Fig-8.8. H-Bridge Inverter

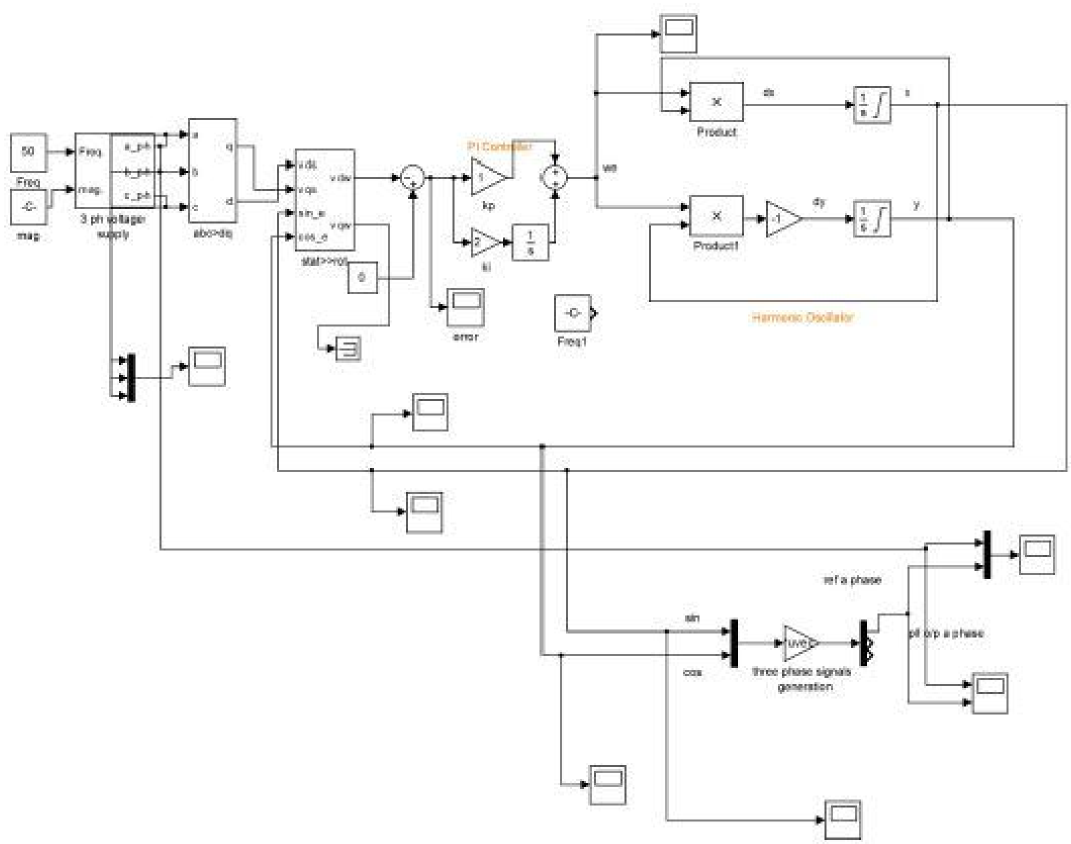

Fig-8.9. Simulink model of PLL

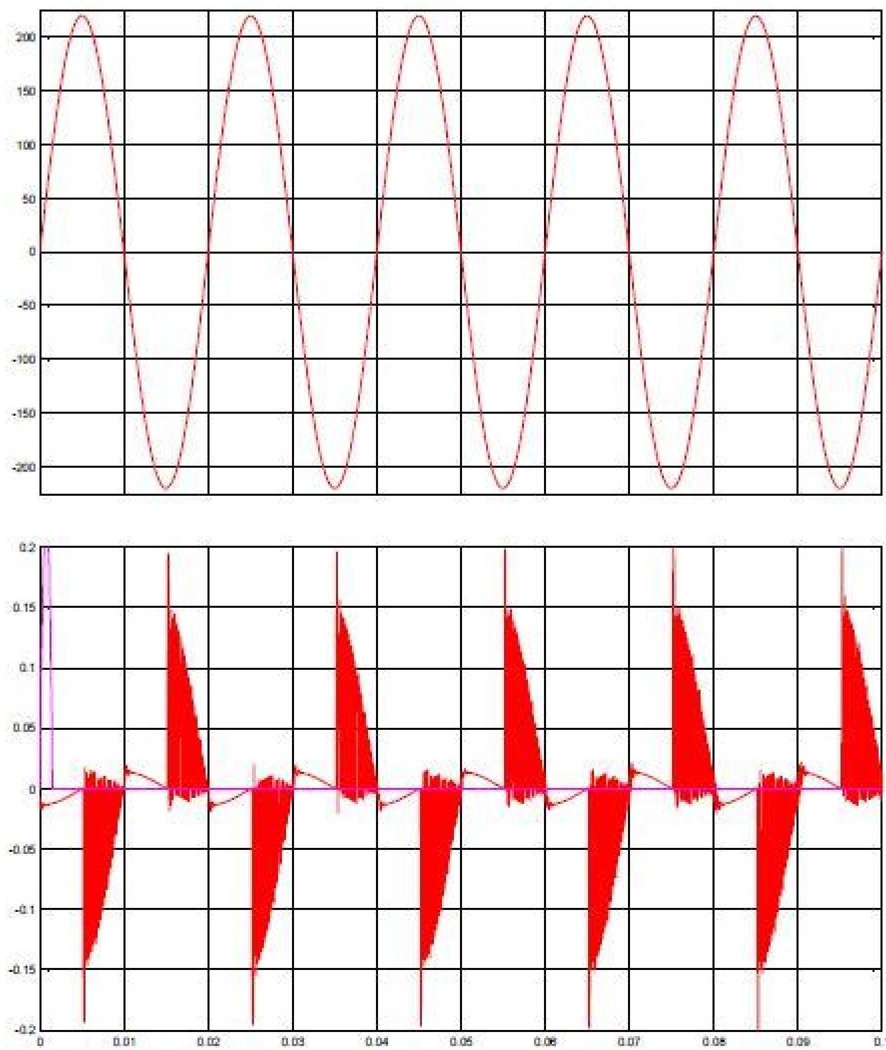

Fig-8.10. output of the inverter

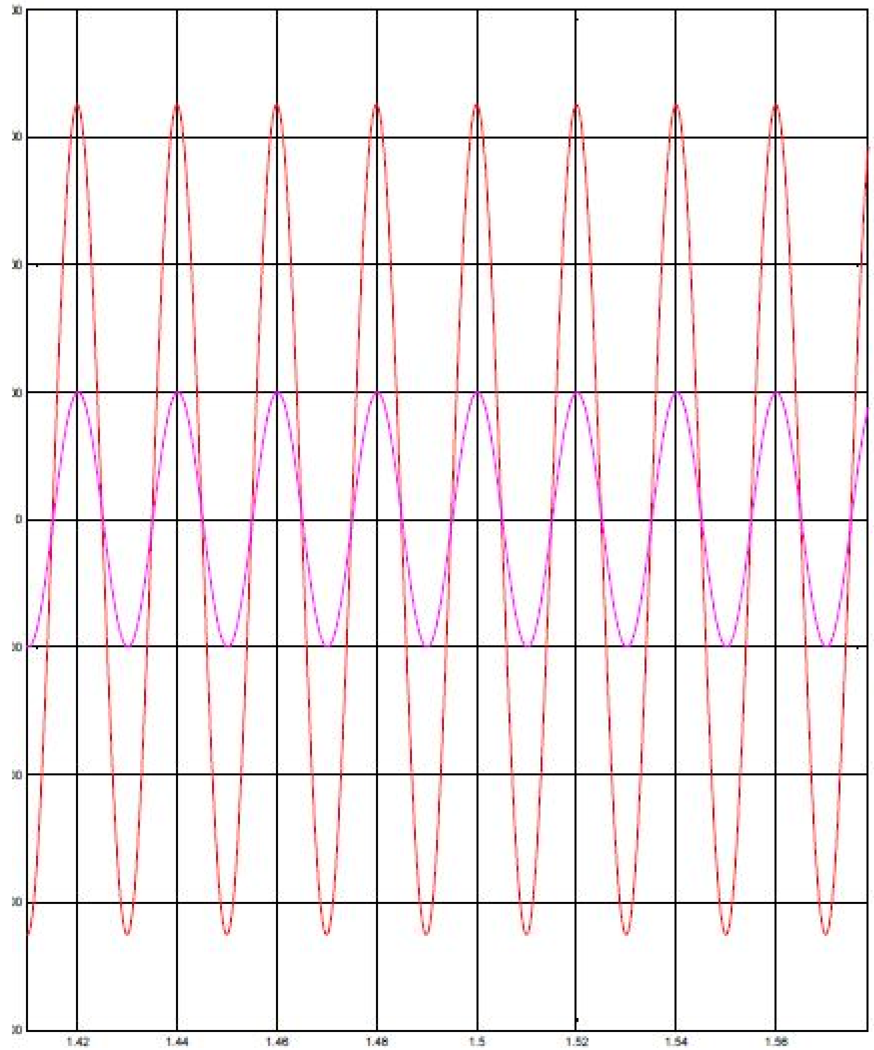

Fig.8.11. Grid voltage output

CONCLUSION

A PWM generator was utilized for generating the pulse signal that was compared with the signal generated from the MPPT unit to give out the gating signal to the switch.

If MPPT had not been used, then the user would have had to input the duty cycle to the system. When there is change in the solar irradiation the maximum power point changes and thus the required duty cycle for the operation of the model also changes. But if constant duty cycle is used then maximum power point cannot be tracked and thus the system is less efficient.

The various waveforms were obtained by using the plot mechanism in MATLAB. There is a small loss of power from the solar panel side to the boost converter output side. This can attributed to the switching losses and the losses in the inductor and capacitor of the boost converter.

The parameters of the inverter model like the inductance, the dc gain (kv) and time constant (tv) considerably affect the system dynamics at the switching time and should be chosen properly to obtain a stable periodic behavior. When instead of PV, DC source is connected the voltage waveform is quite similar to the reference voltage but both current and voltage has some harmonic content in them. After connecting the PV module the harmonic content in current and voltage increased and the output of the PV was also affected considerably.

A Linear PLL (LPLL) is used for synchronization for single phase signals with acceptable results and a Synchronous Reference Frame (SRF) PLL is used for 3-phase balanced signals. But it cannot be used for unbalanced utility conditions as the detected phase angle contains 2nd harmonic oscillations.

9.1. FUTURE WORK

Improvement to this project can be made by reducing the harmonics during synchronization with the grid. Algorithm for SOGI PLL to be applied to obtain less harmonic oscillation during steady state and transient conditions. Analyzing fast algorithms to track the phase angle during abnormal grid conditions.

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